# High-precision Point Cloud Data Acquisition for Robot Based on Multiple Constraints

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July 5, 2023

# Outline



- Background
- Methodology
- Experimental Analysis
- Comparative Analysis
- Conclusion

# Background




Coordinate Measuring Machine （CMM)

Roughness profilometer

Large size
Many features
……

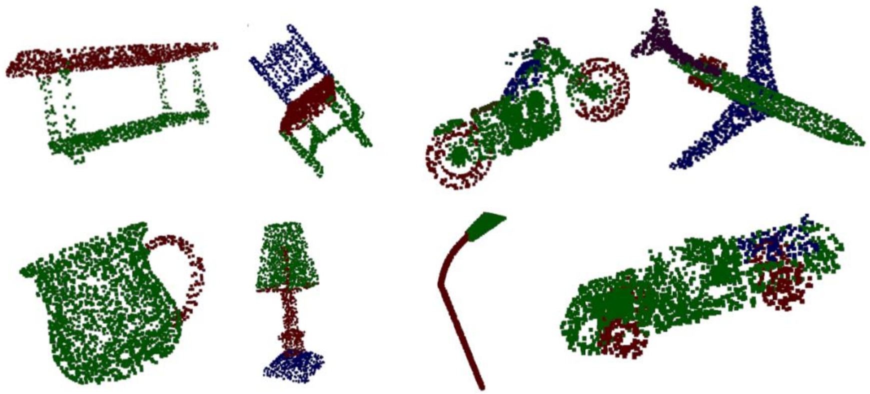
Cabinet type parts

Single point measurement
Requires contact with the workpiece

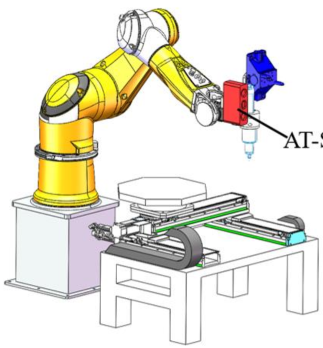
The Challenge of Contact Measurement：
Slow speed、 Expensive、 Size limitation

# Background





Point cloud measurement data




Robot measurement system

Large parts need to be measured several times and joined together to form a whole

**Advantages of point cloud measurement:**

**Convenient operation. Fast speed. Big data**

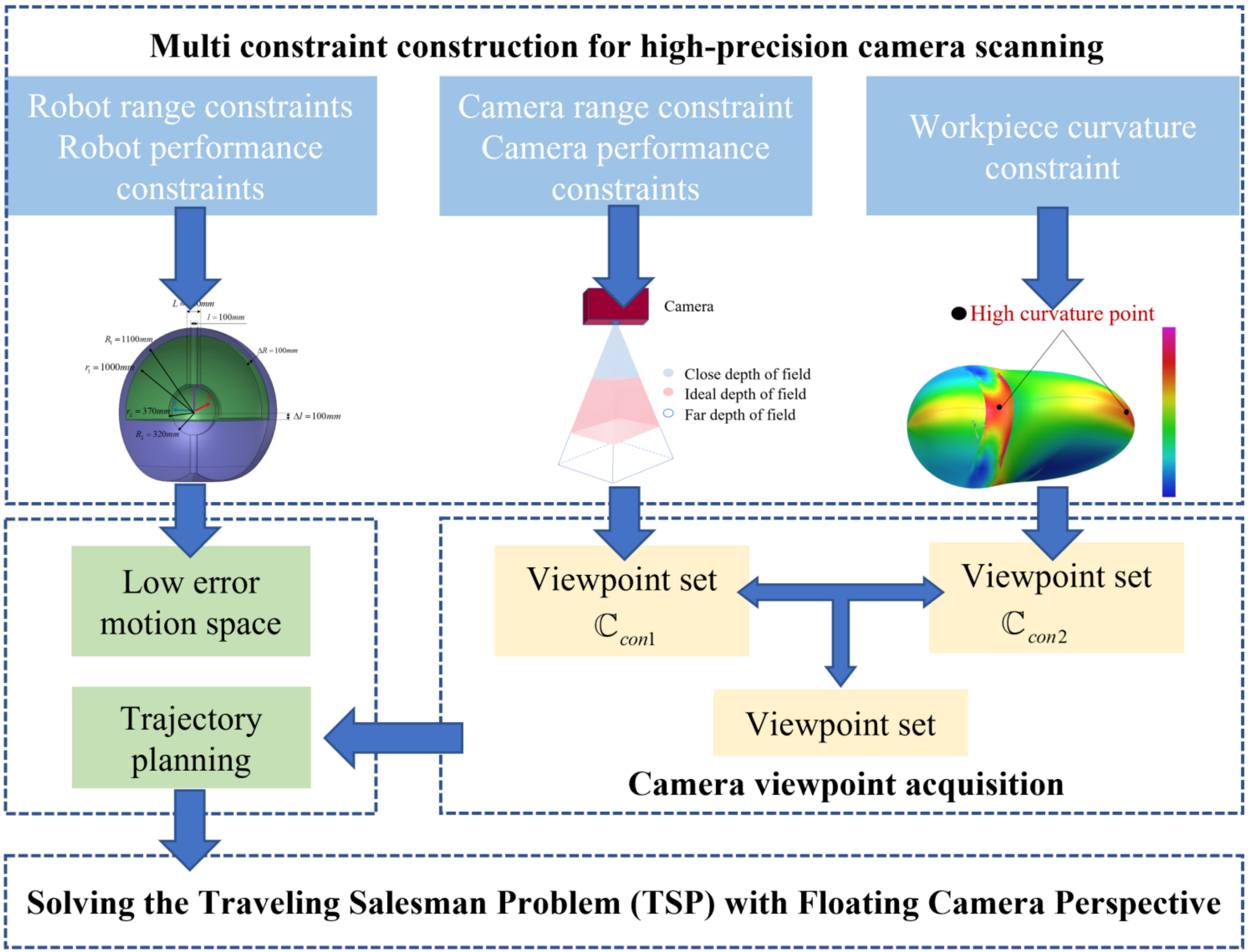
**The challenge of point cloud measurement based on robots:**

**Limited accuracy、 High environmental dependence**

# Methodology



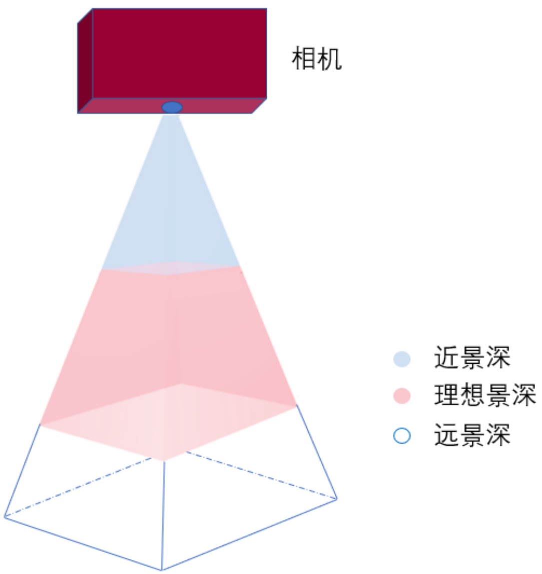
## Overall Logic



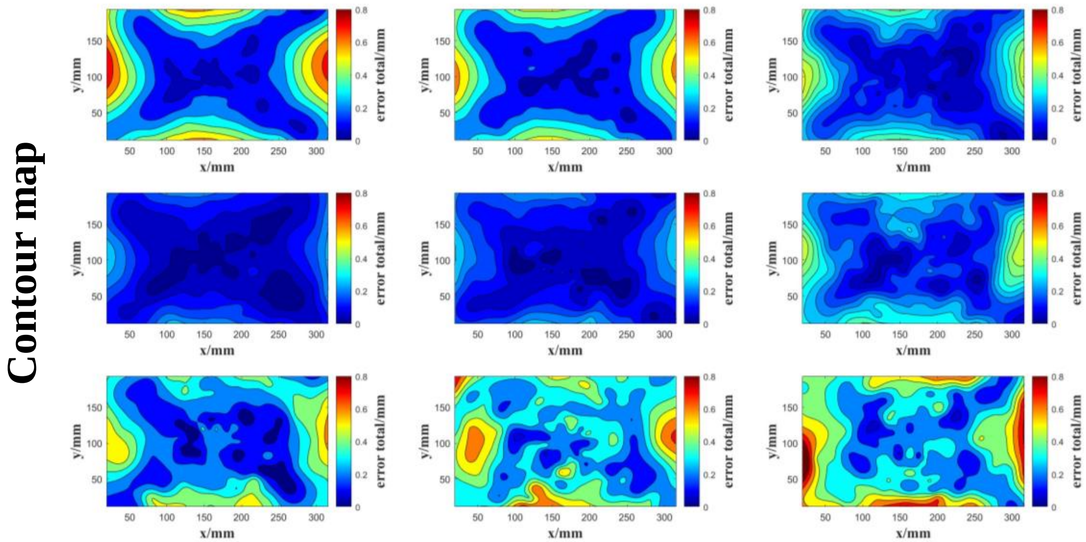
# Methodology

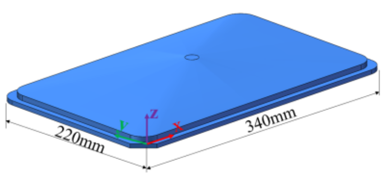


## ☐ Camera Performance Constraints——*Measurement*

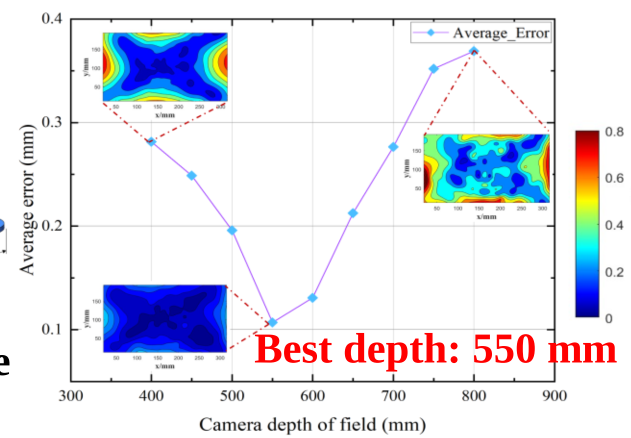



Measurement depth




Standard workpiece



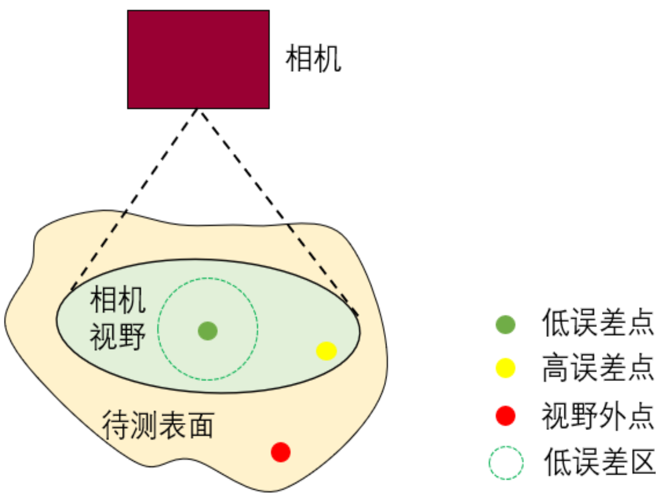

Scanning errors at different heights from [400,800], step 50 mm

**For the camera under study, the optimal measurement depth is 550 mm**

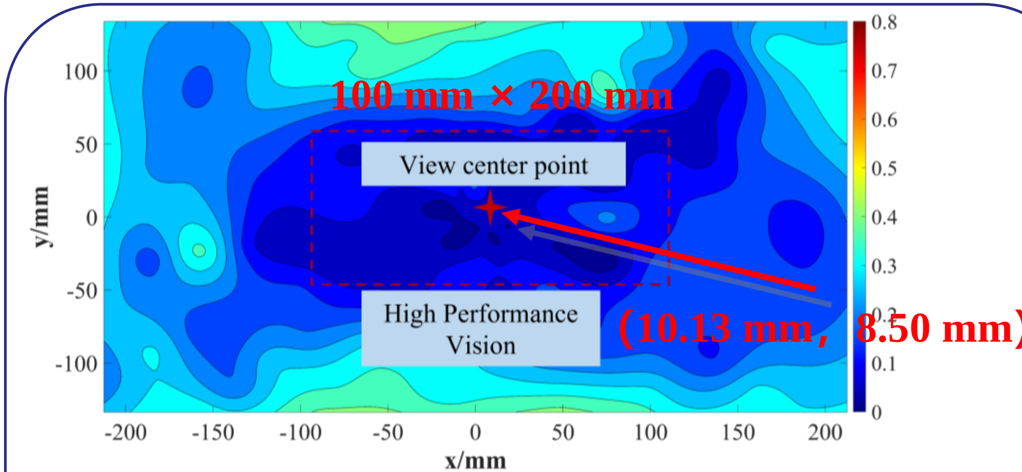
# Methodology



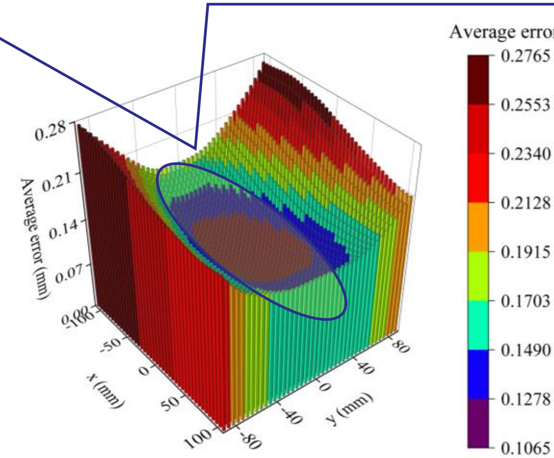
## □ Camera Performance Constraint——*Measurement*




Field of view




**Find the low error zone of camera by using the sliding-window**




**For the camera under study, the optimal measurement zone is determined**

# Methodology

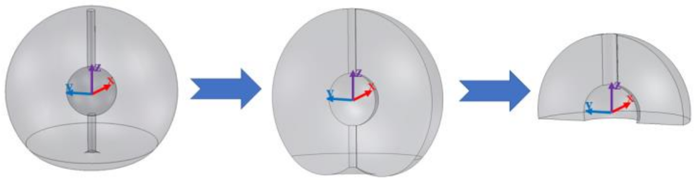


## ◻ Robot Error Constraint——*Motion*

**Least Squares method** $Y = AX$

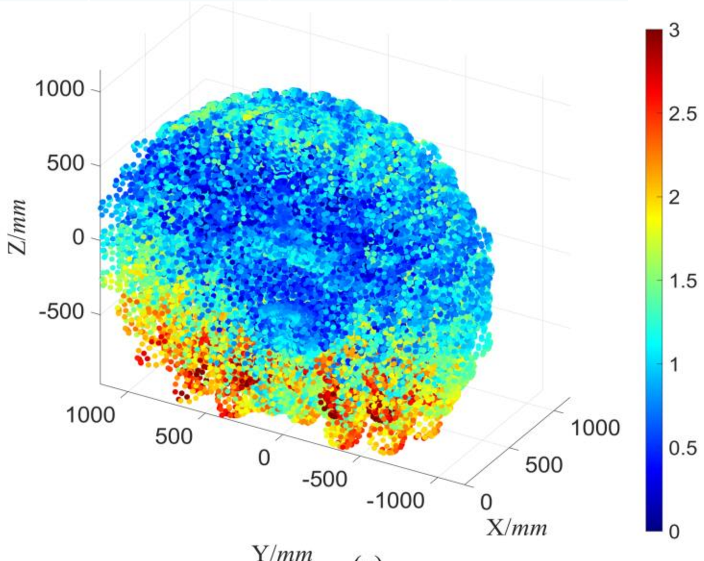
**Theoretical and practical kinematic parameters**

| 连杆 | $a_i(mm)$ | $d_i(mm)$ | $\alpha_i(\text{deg})$ | $\theta_i(\text{deg})$ |
|---|---|---|---|---|
| **1** | 50/49.327 | 0/-0.051 | -90/-89.995 | 0/-0.051 |
| **2** | 500/500.318 | 0/0.090 | 0/0.015 | -90/-89.916 |
| **3** | 0/-0.256 | 50/50.090 | 90/90.012 | 90/90.011 |
| **4** | 0/0.091 | 550/549.898 | -90/-90.017 | 0/0.044 |
| **5** | 0/0.049 | 0/0.135 | 90/90.001 | 0/-0.023 |
| **6** | 0/-0.159 | 100/99.887 | 0/-0.032 | 0/-0.071 |

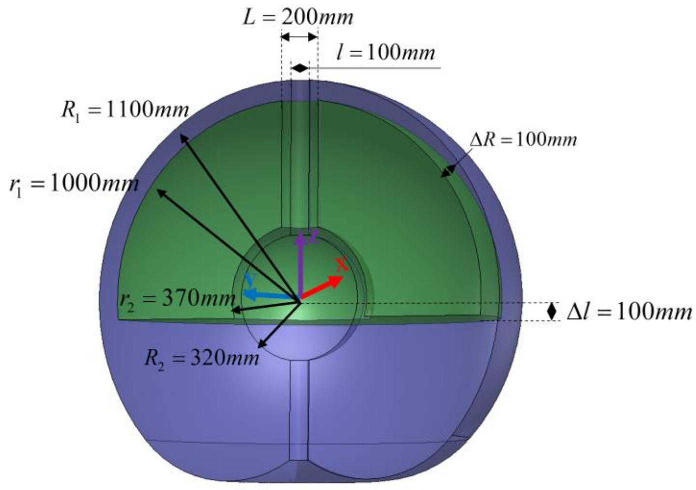


**Motion space→ Work space → Performance space**

**Simulate the Position Error in the motion space of the Staubli TX2-90L.**




(a)




(b)

**(a) Position error of robot Work space. (b) Robot performance space.**

# Methodology

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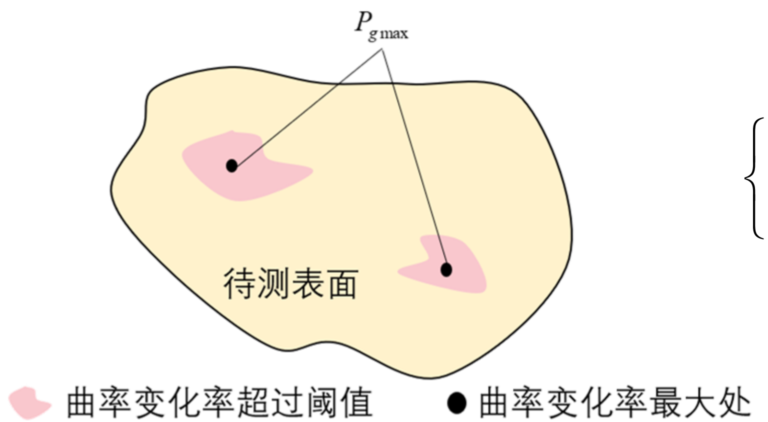
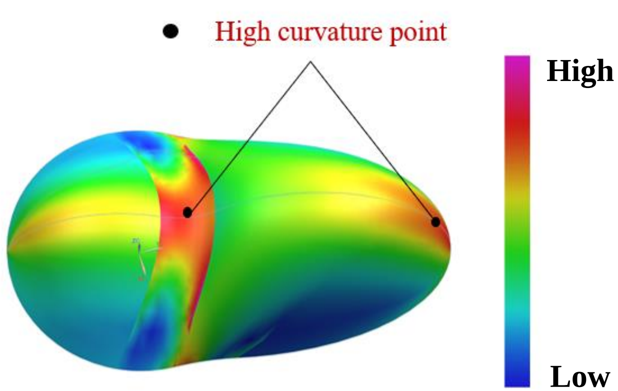
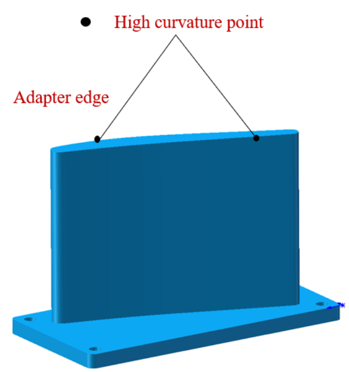
## ☐ Curvature Constraint——*Workpiece*

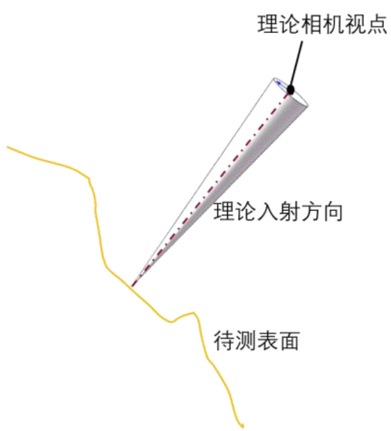



$$\begin{cases} g_i \geq g_h & \text{Add sampling points} \\ g_i < g_h & \text{No need to add sampling points} \end{cases}$$




**Schematic diagram of curvature change area**




**Viewpoint Cone**

***Weaken the vertical constraint***

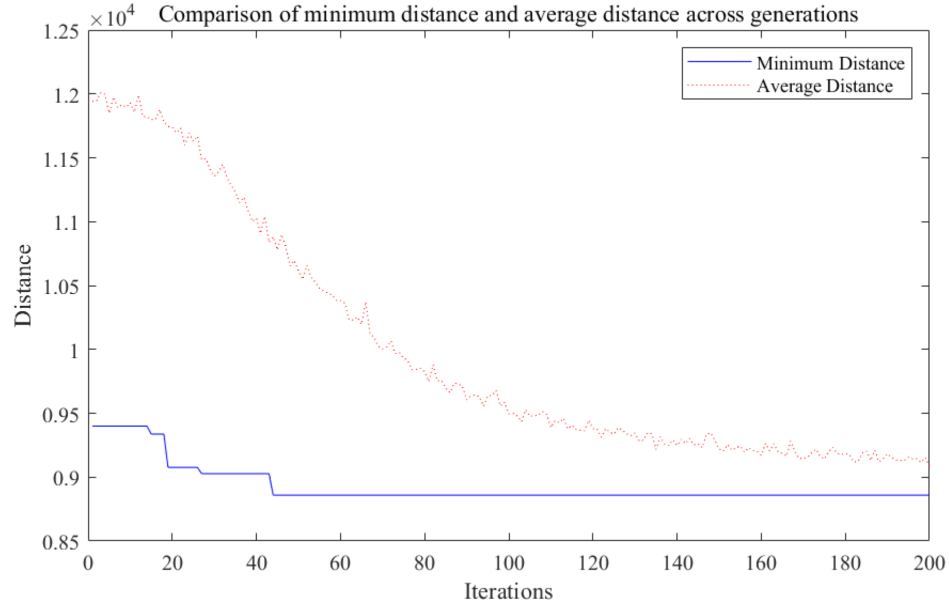
**Designing strategies to increase scanning points for high curvature areas**

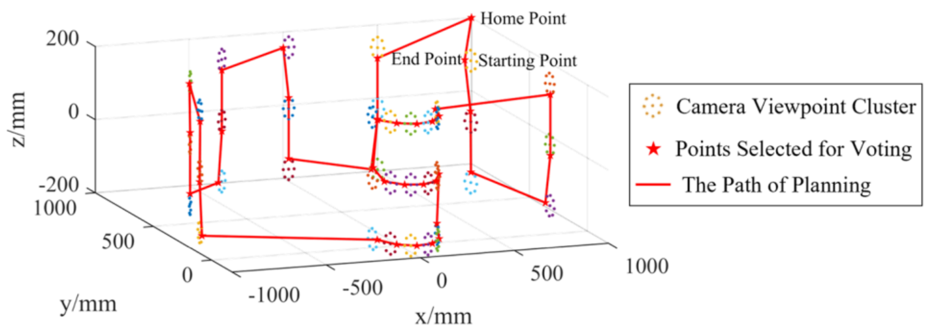
# Methodology



## ☐ Camera Viewpoint Trajectory Planning

$$
\begin{cases}
\min & F({}^{u}p(x,y,z)) = \sum_{i=1}^{N} \left\| {}^{B}p_{ir}(x,y,z) - {}^{B}p_{it}(x,y,z) \right\| \\
 & E(h,\ w) = \iint_{s} \varepsilon ds \qquad (ds = dhdw) \\
s.t. & N = N_1 + N_2 \\
 & N_1 = \sum_{k=1}^{m} \left( \left[ \dfrac{H_{uk}}{h_{good}} \right] \cdot \left[ \dfrac{W_{uk}}{w_{good}} \right] \right) \\
 & N_2 = \sum_{j=1}^{n} N_{\Omega j} (when : g_i \geq g_h, default : N_{\Omega j} = 1) \\
 & \dfrac{D}{D_{\max}} = \dfrac{h}{h_{\max}} = \dfrac{w}{w_{\max}} \\
 & D_{\min} \leq D \leq D_{\max} \\
 & {}^{B}p(x,y,z) = {}^{B}_{u}T \cdot {}^{u}p(x,y,z) \\
 & {}^{B}p_{ir}(x) \geq 0
\end{cases}
$$




Trajectory Planning of Ant colony-voting algorithm

**Algorithm iteration to obtain the optimal scanning path**

# Experimental Analysis

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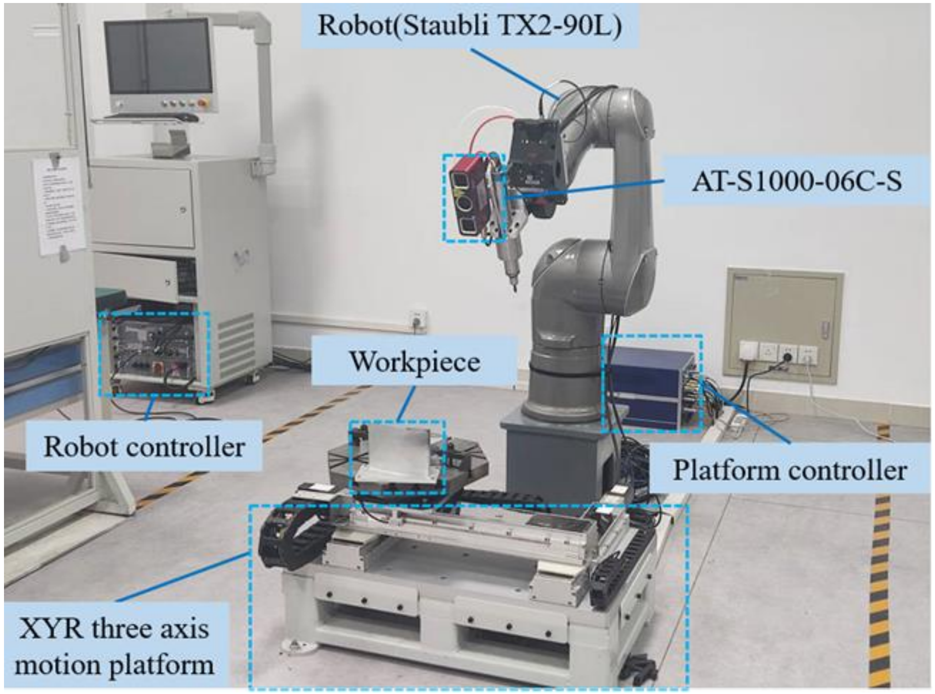
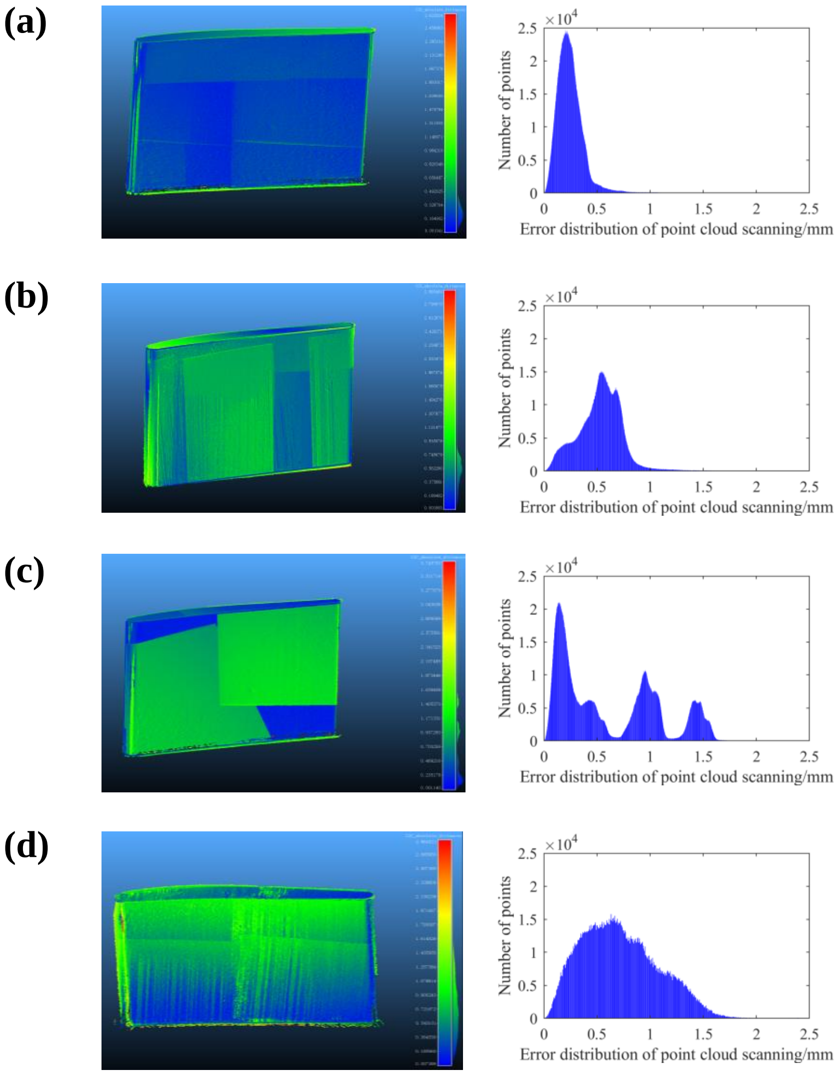



**Experimental site of robot measurement system**

| ID | Constraints imposed | Mean value/mm | Variance |
|---|---|---|---|
| **(a)** | With multiple constraints | **0.249** | **0.135** |
| **(b)** | Without camera constraints | 0.539 | 0.225 |
| **(c)** | Without robot constraints | 0.616 | 0.478 |
| **(d)** | Without workpiece constraints | 0.726 | 0.364 |




## Results Under Multiple Constraints

# Comparative Analysis

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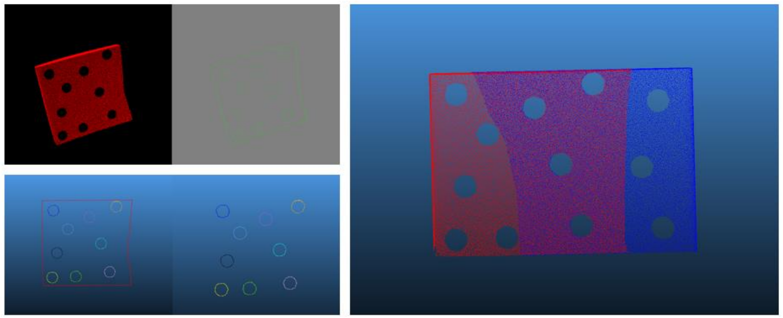
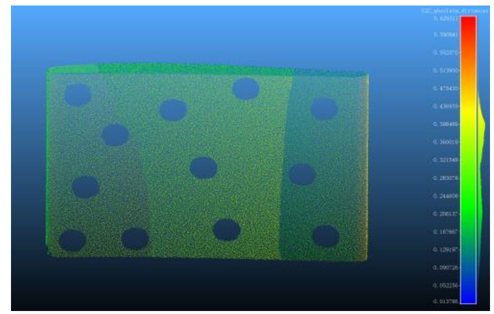
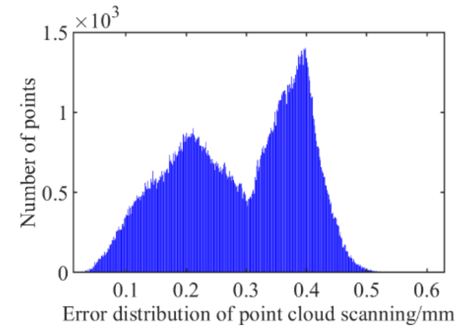
## The Marked Points Method








Boundary extraction, segmentation, fitting → Point Cloud Registration Results

**Mean value: 0.288mm**

## Intelligent Alignment Algorithm

| Registration Method | Evaluating Indicator | |
|---|---|---|
| | Fitness | RMSE |
| Global registration FAST | 0.071 | 0.377 |
| Global registration RANSAC | **0.643** | **0.489** |
| ICP(P2P) | 1.000 | 1.834 |
| ICP(P2Plane) | 0 | 0 |
| FAST+ICP(P2Plane) | 0.463 | 0.258 |
| RANSAC+ICP(P2Plane) | **0.624** | **0.253** |
| CPD | 1.000 | 3.129 |
| PCA | 0.915 | 2.676 |

**Proposed method has an average error of 0.249 mm, which is superior to the other method.**

# Conclusion



A high-precision point cloud scanning technique based on Multiple Constraints is proposed.

The high-performance working area of a measurement system is obtained by imposing constraints on both the measuring system and the workpiece to be measured.

The data acquisition accuracy of proposed method can reach 0.249 mm, which is better than the marker point method and other intelligent registration algorithms.

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# Thanks for listening!

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July 19, 2024